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Reliability of the kinetics of British Army foot drill in untrained personnel

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Title: Reliability of the Kinetics of British Army Foot-Drill in Untrained Personnel

Running head: Reliability of the Kinetics of Foot-Drill

Authors: Alex J Rawcliffe¹, Richard J Simpson², Scott M Graham¹, Stelios G Psycharakis³, Gavin L Moir⁴
and Chris Connaboy⁴

Institutional affiliations:

¹School of Life, Sport & Social Sciences, Edinburgh Napier University, UK

²Department of Health and Human Performance, University of Houston, Houston, USA

³Institute of Sport, Physical Education and Health Sciences, University of Edinburgh, UK

⁴Exercise Science Department, East Stroudsburg University, USA

⁴Neuromuscular Research Laboratory, University of Pittsburgh, USA

Corresponding author: Alex J Rawcliffe, School of Life, Sport & Social Sciences, Edinburgh Napier
University, Sighthill Campus, Sighthill, EH11 4BN, UK

ABSTRACT

The purpose of this study was to quantify the reliability of kinetic variables of British Army foot-drill performance within untrained civilians and report the magnitude of vertical ground reaction force (vGRF) and vertical rate of force development (RFD) of foot-drills. Fifteen recreational active males performed three testing sessions across a 1-week period, with each session separated by 24 h. Within each testing session participants (mean \pm SD; age 22.4 ± 1.7 years; height 177 ± 5.6 cm; weight 83 ± 8.7 kg) completed ten trials of stand-at-attention (SaA), stand-at-ease (SaE), halt, quick-march (QM) and a normal walking gait, with vGRF and vertical RFD measured on a force plate. Between and within session reliability was calculated as systematic bias, coefficient of variation calculated from the typical error ($CV_{te}\%$) and intra-class correlation coefficient (ICC). Significant ($P \leq 0.05$) between session differences were found for the vGRF SaA, SaE and vertical RFD SaA, SaE conditions. Significant ($P \leq 0.05$) within session differences were found for the vGRF SaA and SaE conditions. A mean vGRF $CV_{te}\% \leq 10\%$ was observed across all foot-drills. However, the mean vertical RFD $CV_{te}\%$ observed was $\geq 10\%$ (excluding SaE) across all foot-drills. The ICC analyses indicated that the vGRF Halt, QM, SaA and Walk condition achieved moderate to large levels of test-retest reliability, with only SaE failing to achieve an ICC value ≥ 0.75 . The vertical RFD QM, SaE, and Walk condition achieved moderate levels of test-retest reliability, with Halt and SaA failing to achieve an ICC value ≥ 0.75 . It was determined that a single familiarization session and using the mean of eight-trials of vGRF are required to achieve acceptable levels of reliability.

KEY WORDS: Military, Training, systematic bias, within-subject variation, test-retest reliability

INTRODUCTION

Lower-limb musculoskeletal (MSK) overuse injuries are defined as the single most significant medical impediment to the physical readiness of recruits within the British Armed Forces [23] and the most common cause of medical discharge from the British Army (MOD, 2015). Training status specific rate of medical discharges for untrained recruits (52.2 per 1,000 personnel) is significantly greater in comparison with trained personnel (11.8 per 1,000 personnel) [1]. The high rates of medical discharge of untrained personnel reflect both the intensive physical nature of basic military training (BMT), and lack of exposure to the rigorous physical demands of high training loads specific to the BMT course [1]. Efforts to reduce and/or minimise the incidence of lower-limb MSK overuse injuries and disorders is of primary focus for many military organisations worldwide.

British Army foot-drill is a fundamental military occupational activity, routinely practised by recruits during BMT, and utilised to enhance discipline, co-ordination, and body awareness [7]. Organised foot-drill sessions for recruits have been reported to range from 40 min to 80 min sessions per day [30] up to a total of 13h per week [5]. Each foot-drill contains a number of key performance markers which define that particular foot-drill. For example, quick march (QM) requires marching at two paces per second whilst repeatedly impacting the ground with an exaggerated heel strike. Other regimented movements performed while marching involve an exaggerated stamp of the dominant or non-dominant foot (depending on foot-drill performed) onto the surface of the ground. Foot-drills such as stand-at-attention (SaA), stand-at-ease (SaE) and Halt, involve flexion at the hip to 90° followed by an exaggerated stamping of the foot onto the ground, landing with the knee in an extended position. Selective British Army foot-drill has previously been shown to produce high impact loading forces within soldiers who have been trained in foot-drill (trained) [5] and recruits who have not (untrained) [5, 9]. To date, only two biomechanical studies have quantified the impact loading forces of selected foot-drills within an untrained sample. Using the mean of 3 trials, Carden *et al.*, [5] reported high vertical ground reaction forces (vGRF) for march, halt, stand-at-attention (SaA) and stand-at-ease

(SaE); ranging from 1.3BW to 4.4BW, and high loading rates; ranging from 70BW/s to 499BW/s. Connaboy *et al.*, [9] reported similar mean vGRF (3.06 ± 1.16 BW) and vertical rate of force development (RFD) (187.7 ± 94.2 BW/s) values for the same foot-drills using the mean of 5 trials. Both studies illustrate impact loading forces similar to those experienced during high level plyometric exercises; a modality of training more commonly associated with highly trained athletic populations [4].

However, although Connaboy *et al.*, [9] and Carden *et al.*, [5] investigated the impact loading forces of foot-drill, the number of trials utilised to accurately assess ground reaction force (GRF) variables of foot-drill was selected arbitrarily, with no justification regarding the requirement for any familiarisation sessions and/or trials prior to data collection, and no rationale for the mean number of trials used to represent the forces achieved. Using too few trials to assess biomechanical variables of foot-drill may not reliably represent the individual's true performance. Consequently, the stability and reproducibility of mean values could be questioned as the magnitude and influence of variability within previous foot-drill data was not calculated. The sources of error that contribute to the overall reliability of the measure primarily consist of biological, and technological – with a reliable test characterised by low within-subject variation and high test-retest correlation [16, 22]. Analysing the magnitude of a systematic bias, within-subject variation, and test-retest correlation of foot-drill will provide valuable information that will better inform future biomechanical studies of foot-drill in terms of the necessary number of trials required to obtain accurate and stable measures of foot-drill performance, and the requirement of any familiarisation sessions and/or trials prior to analysing the impact loading forces of foot-drill within an untrained sample.

Therefore, the aims of the present study were three fold: (i) to determine the magnitude of any systematic bias among session(s) and between trial(s), (ii) to establish the within-subject variation of key biomechanical variables; and (iii) to analyse the test-retest reliability to indicate the number of

sessions and/or trials required to maximise the possibility of identifying changes in the kinetics of British Army foot-drill between different conditions, and over time.

It was hypothesized that similar to other locomotor and landing tasks, several trials would be necessary to achieve high levels of performance stability during British Army foot-drill, and that familiarisation sessions and/or trials would be required prior to collecting stable foot-drill biomechanical data. In addition, it was hypothesized that as random error decreased, test-retest correlation scores would increase when using the average of multiple trials.

METHODS

Experimental Approach to the Problem

A within-participant repeated-measures study design was employed to assess measures of reliability; establishing the requirement for familiarisation sessions and/or trials to determine within-subject variation and test-rest reliability.

Participants

Fifteen recreational active healthy males (mean \pm SD; age 22.4 ± 1.7 years; height 177 ± 5.6 cm; body mass 83 ± 8.7 kg) with no pathological lower-limb, hip or spinal conditions volunteered to participate in the present study. Study participants were recreationally active, taking part in moderate physical activity and/or sport a minimum of two-to-three times per week over the previous three years [11]. Ethical approval for the present study was gained from the local ethics committee. Written informed consent was obtained from each participant prior to data collection. Study participants were defined as “untrained” as they did not obtain any previous training of British Army foot-drill prior to this study. Nevertheless, the study participants obtained similar anthropometric characteristics and training histories when compared with male entry-level recruits [21, 28].

Procedures

During each of the three 90 min testing sessions, ten acceptable trials [20] of five British Army foot-drills involving; SaA, SaE, QM, Halt and a normal walking gait were collected from each participant independently. Acceptable trials were those that conformed to the key performance markers as described in the British Army Drill Instructors Manual (BADIM) [2]. Furthermore, if obvious adjustments in foot-drill movements were identified, those trials were discarded and repeated. Ten trials of a normal walking gait were collected on each day of testing to act as a comparison with QM. Foot-drill data was collected on three non-consecutive days. All three test sessions were conducted at the same time of day and performed under the guidance of the same instructor. Participants were asked to avoid practicing foot-drill throughout the testing period and to refrain from strenuous, high impact loading activity 24 hours prior to each test session.

Each participant was fitted with a size-specific pair of Hi-Tech Silver Shadow™ training shoes (TR) to reduce the influence of different shock absorbing properties of different footwear on force plate data [12]. Each participant performed a standardised 10 min warm up whilst wearing the TR, consisting of 5 min on a cycle ergometer (Monark Exercise AB, 824-E, Sweden), cycling between 60-70 revolutions per minute under a 1.5kg breaking force, followed by various dynamic lunging and squatting movements prior to each test session [27]. Foot-drill and walk were performed on two embedded (side-by-side) Kistler force plates (Kistler Instruments AG, 9281CA, Switzerland) - interfaced with BioWare 3.2.5 software to record and analyse the vGRF and vertical RFD of each foot-drill and walk. The force plate was set at a sampling frequency of 1000Hz with a 3 sec capture period [13, 25]. Force data were collected using an eight channel 16-bit analogue to digital converter (Qualisys, 8128, Sweden). The vGRF values were normalised to bodyweight (BW) to enable direct comparison across participants.

Representative of an entry-level recruit, foot-drill was a novel task for all participants prior to data collection. Furthermore, a combination of action observation and physical practice in accordance with

the BADIM [2] was utilised as a means of demonstrating and teaching foot-drill. Study participants were given a 3 sec countdown prior to the execution of each foot-drill. Specific to QM, participants were instructed to QM with an exaggerated heel strike across the 10-m walkway [6]. During the execution of SaA, SaE, and Halt, study participants were instructed to flex their hip to 90° and land with an exaggerated stamp onto the surface of the force plate with the knee in an extended position. Study participants kept their head and eyes forward as to minimise visual fixation (targeting) of the force plate during all foot-drill trials [6]. During the initial testing session only, study participants were given 15 min to practice the five foot-drills prior to data collection and become familiar with the TR.

A 90 sec recovery period between each of the 10 trials and a 15 min recovery between foot-drills was employed to reduce the risk of fatigue on foot-drill performance [4]. Ten trials were collected for each of the five foot-drills during each of the 3 test sessions. A total of 30 trials were analysed for each of the five foot-drills. Accumulatively, 150 (acceptable) trials were collected and analysed per participant. As a means of enhancing the internal validity of the present study whilst minimising an order effect, foot-drill was counterbalanced for each participant across all three testing sessions [6].

Key performance markers of British Army foot-drill

A comprehensive description of each foot-drill analysed within the present study can be found in the BADIM [2]. The foot which strikes the force plate during each of the foot-drills is referred to as the active limb with the opposite limb referred to as the support limb (table 1).

Table 1 - Regimented foot-drill manoeuvres (BADIM, 2009)

Foot drill	from QM	from SaE	from SaA	active Limb
QM				R
Halt	X			R
SaA		X		L
SaE			X	L
Walk				R

Table 1 illustrates the regimented foot-drill manoeuvres completed from their respective foot-drill, identified by X. The active limb refers to the left (L) or right (R) limb that is used in each foot drill.

Ten trials of a normal walking gait were included in the analysis for each participant as to compare with the biomechanical variables of QM. Walking, performed by each participant at their preferred walking speed, was measured in meters per second and was standardised for each individual participant via timing gates (Fusion sport, SmartSpeed, Australia) located at 0-m, 5-m and 10-m along the 10-m walkway. The velocity of walking was monitored across each test session and a maximum deviation of +/- 5% was allowed from each participants walking velocity [28]. Foot-drill vGRF data were exported via BioWare 3.2.5 system and filtered via a low-pass 4th order zero-lag (single bi-directional) Butterworth filter, using a cut off frequency of 50Hz based on previous power spectrum analysis, ensuring 95% of the signal content was retained [32].

The BW normalized vGRF was calculated as,

$$BW_{Norm} = \frac{F_{Zpeak}}{BW} \quad [1]$$

where, BW_{Norm} is the normalized vGRF expressed in BW, F_{Zpeak} is the peak vertical ground reaction force measured in Newtons (N), and BW is the participant's bodyweight expressed in N determined via the force plate. The kinetic variables of interest were defined and calculated as follows: F_{Zpeak} - defined as the highest (Peak) vertical ground reaction force (measured in Newtons (N)) of each foot-drill.

Time to F_{Zpeak} - defined as the time to reach F_{Zpeak} expressed in milliseconds (ms).

$$Time\ to\ F_{Zpeak} = t_{max} - t_{min} \quad [2]$$

where, t_{min} represents the time point of the initial onset of vGRF and t_{max} represents the time point of F_{Zpeak} , measured in sec. The initial onset of vGRF was defined as when the vGRF component exceeded a threshold of 20N [24]. The vertical RFD was calculated as;

$$RFD = \frac{\Delta F}{\Delta T} \quad [3]$$

where, *RFD* is the rate of force development measured in N per second (N/s), ΔF represents the change in force measured in N and, ΔT represents the change in time measured in sec [2].

Vertical RFD was normalised relative to participant's BW calculated as,

$$Norm\ RFD = \frac{RFD}{BW} \quad [4]$$

where, *Norm RFD* is the vertical RFD normalised to the participant's bodyweight, measured in N.

Statistical Analyses

Prior to calculating systematic bias, within-subject variation and, test-retest correlation, each of the biomechanical variables was examined for heteroscedasticity [3]. If heteroscedasticity was not present and showed no departures from a normal distribution, the raw data were used in the reliability calculations. However, if the data were found to be heteroscedastic, and shown to violate the assumption of normality, then data were log transformed in SPSS 20 using 100x natural logarithm of the observed value [3, 16]. To isolate the effects of the between-session and within-session systematic bias only the remaining two testing sessions and the initial 8 trials from each session were included in the subsequent reliability analyses (within-subject variation and test-retest correlations).

Systematic bias was determined using a repeated-measures analysis of variance (RM ANOVA) design. Multiple ($n = 5$) one-way RM ANOVA's with Bonferroni adjusted multiple comparisons were conducted for each of the predictor variables (vGRF and vertical RFD) for each of the foot-drills. This analysis was utilised as a means to determine whether the magnitude of difference among the mean values for each session ($n = 3$) and trial ($n = 10$) was statistically significant. Alpha (α) value was set at 0.05. Where any statistically significant differences between-session and/or within-session occurred, those sessions and/or trials were removed from further calculations of reliability (within-subject variation and test-retest correlations). The within-subject variation was calculated for the remaining marching drill trials that did not contain any systematic bias. The within-subject variation was reported for the remaining trials as both the typical error and coefficient of variation of the typical error (CV_{te}). The

within-subject variation was expressed as a percentage of the coefficient of variation of the typical error (CV_{te}%). The CV_{te}% was calculated using the methods proposed by Hopkins, [16] and were calculated as;

$$CVte\% = \left(\frac{TE_n}{M_n} \right) \times 100 \quad [5]$$

where TE_n is the typical error of *n* number of trials and M_n is the mean value from the same *n* repeated trials.

Test-retest reliability was calculated for all acceptable trials for each foot-drill and evaluated using the ICC (Model 3,1) [3, 17]. The stability of the variation in each predictor variable was assessed using methods proposed by James *et al.*, [20]. Trials that contained a systematic bias were removed with the remaining trials used to calculate maximum ICC values. Initial ICC was calculated for all data to establish maximum ICC values and 95% confidence intervals (CI). An iterative process was then conducted by which ICC values were calculated for the initial 3 trials up to the maximum number of acceptable trials per foot-drill [17]. To assess the stability of each predictor variable, the minimum number of trials required to achieve maximum levels of ICC were calculated. Furthermore, to determine the minimum number of trials necessary to achieve a stable representation of the variation within each predictor variable, the number of trials required to achieve an ICC value of 0.75, 0.80 and 0.85 were calculated.

RESULTS

Systematic Bias

Statistically significant between-session differences were found for the vGRF and vertical RFD in the following foot-drills: vGRF SaA condition ($F_{2, 28} = 9.603$, $P = 0.001$, $Np^2 = .407$), vertical RFD SaA condition ($F_{2, 28} = 7.152$, $P = .003$, $Np^2 = .338$), vGRF SaE condition ($F_{2, 28} = 7.242$, $P = .003$, $Np^2 = .341$), and for the vertical RFD SaE condition ($F_{2, 28} = 9.615$, $P = .001$, $Np^2 = .407$). Follow up Bonferroni

comparisons indicated a systematic bias between session 1 and the two remaining testing sessions for the vGRF SaA and SaE, and vertical RFD SaE conditions, with the vertical RFD SaA condition illustrating a systematic bias between session 1 and 3 only (figure 1). No further statistically significant between-session systematic bias was observed for the remaining conditions.

Statistically significant within-session (between-trial) differences were found in the vGRF in the following foot-drills: vGRF SaA condition ($F_{9, 126} = 6.133$, $P < 0.01$, $Np^2 = .305$), vGRF SaE condition ($F_{9, 126} = 4.408$, $P < 0.01$, $Np^2 = .239$), and vGRF Halt condition ($F_{4.9, 68.7} = 2.406$, $P = .046$, $Np^2 = .147$). Bonferroni comparisons revealed a systematic bias in trials 10 for the aforementioned conditions. No further statistically significant within-session systematic bias was observed for the remaining conditions.

Figure 1 – Reliability (systematic bias) of the vGRF and RFD SaA and SaE condition

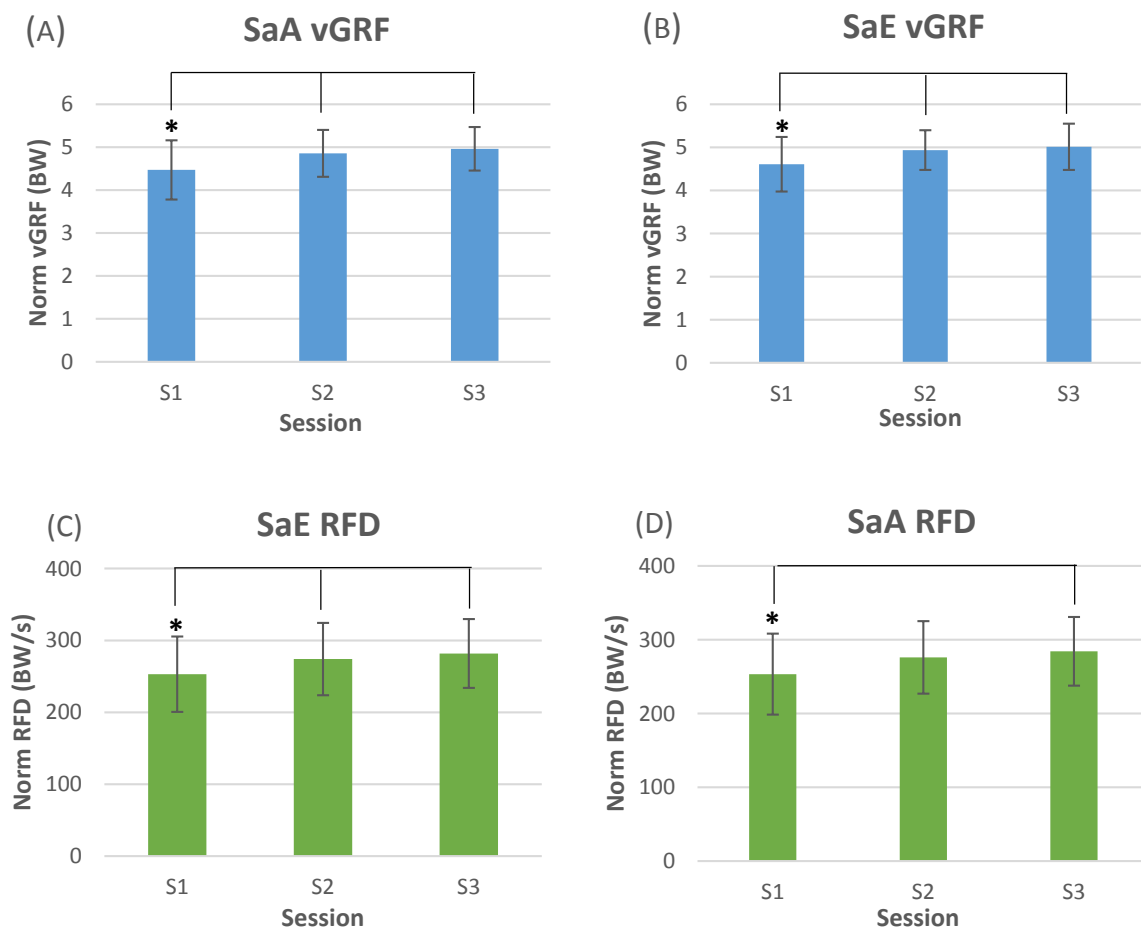
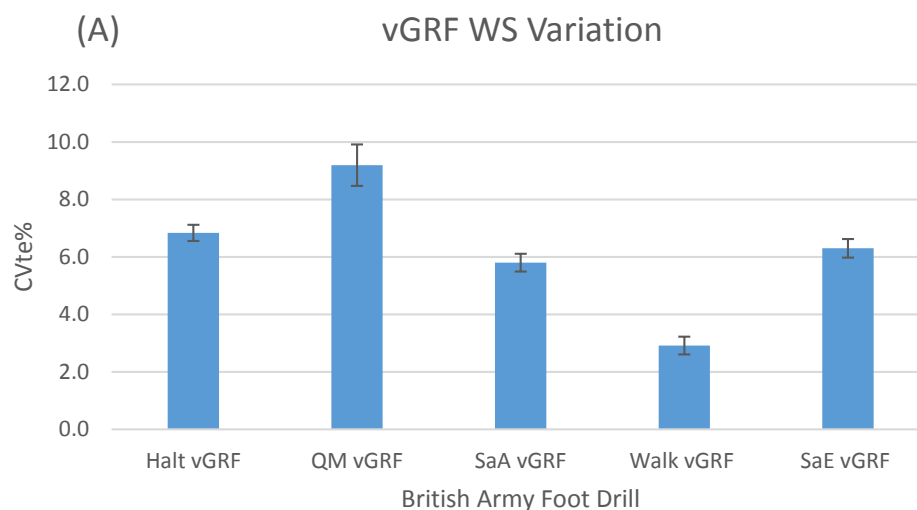


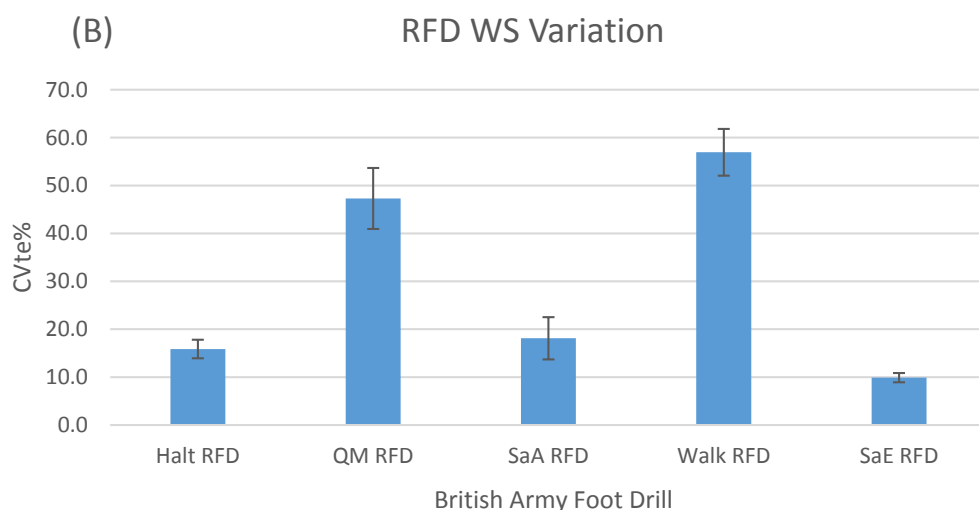
Figure 1: Reliability (systematic bias) of the vGRF and RFD SaA and SaE condition. Mean values for session (1 – 3) for vGRF SaA (A), vGRF SaE (B), RFD SaE, and RFD SaA (D). *Statistically significant difference ($P > 0.05$). Values are session means; bars are SD.

Within-Subject Variation

Table 2 illustrates the magnitude of the $CV_{te}\%$ found within repeated measurements of foot-drill data. Depending on the existence of heteroscedasticity, data were expressed in absolute form (preceded by \pm) or ratio form (preceded by \times/\div) [3, 16]. Figure 2 indicates the magnitude of $CV_{te}\%$ relative to the vGRF variable, showing a mean $CV_{te}\% \leq 10\%$ across all foot-drills (mean \pm SD = Halt: 6.8 ± 0.3 , QM: 9.2 ± 0.72 , SaA: 5.8 ± 0.31 , Walk: 2.9 ± 0.3 , SaE: 6.3 ± 0.32) demonstrating low within-subject variability indicating good reliability. Note however, that in figure 2 the vertical RFD variable expressed a mean $CV_{te}\% \geq 10\%$ (excluding SaE) across foot drills (mean \pm SD = Halt: 15.9 ± 1.93 , QM: 47.3 ± 6.37 , SaA: 18.1 ± 4.4 , Walk: 56.9 ± 4.9 , SaE: 9.9 ± 1.0) demonstrating poor levels of within-subject variability [16].

Figure 2 – WS variation expressed as a $CV_{te}\%$ of the vGRF and RFD across all foot drills





(A): vGRF WS variation, (B): RFD WS variation for all foot drills. Values are session means; bars are SD

Table 2 – vGRF and RFD foot-drill WS variability results

Variable (Units or Ratio)	Trial (n)		TE(n)	TE _{LCL}	TE _{UCL}		%CV	CV _{LCL}	CV _{UCL}
Halt	3	x/÷	1.08	1.06	1.11	x/÷	7.5	5.9	11.2
	4	x/÷	1.07	1.06	1.09	x/÷	7.0	5.6	9.5
	5	x/÷	1.07	1.05	1.09	x/÷	6.6	5.5	8.5
	6	x/÷	1.07	1.06	1.09	x/÷	6.9	5.8	8.6
	12	x/÷	1.07	1.06	1.08	x/÷	7.0	6.3	8.3
	18	x/÷	1.07	1.06	1.08	x/÷	6.8	6.2	7.8
	24	x/÷	1.07	1.06	1.07	x/÷	6.6	6.2	7.4
Halt RFD	3	x/÷	1.23	1.18	1.36	x/÷	23.5	18.0	35.9
	4	x/÷	1.02	1.16	1.27	x/÷	19.8	15.8	27.3
	5	x/÷	1.18	1.15	1.23	x/÷	18.0	14.7	23.5
	6	x/÷	1.17	1.14	1.21	x/÷	16.7	14.0	21.1
	12	x/÷	1.15	1.13	1.17	x/÷	14.7	13.0	17.1
	18	x/÷	1.16	1.15	1.18	x/÷	16.1	14.5	18.1
	24	x/÷	1.16	1.14	1.17	x/÷	15.5	14.2	17.2
	30	x/÷	1.14	1.13	1.16	x/÷	14.3	13.2	15.6
QM vGRF	3	x/÷	1.1	1.08	1.15	x/÷	10.0	7.8	15.0
	4	x/÷	1.11	1.08	1.14	x/÷	10.5	8.5	14.3
	5	x/÷	1.11	1.09	1.14	x/÷	10.6	8.7	13.7
	6	x/÷	1.1	1.08	1.12	x/÷	9.9	8.3	12.4
	12	x/÷	1.1	1.09	1.12	x/÷	10.1	8.9	11.7
	18	x/÷	1.09	1.08	1.1	x/÷	9.1	8.2	10.2
	24	x/÷	1.09	1.08	1.09	x/÷	8.6	7.9	9.5
	30	x/÷	1.08	1.08	1.09	x/÷	8.3	7.7	9.1
QM RFD	3	x/÷	1.55	1.41	1.9	x/÷	55.2	41.2	89.8
	4	x/÷	1.56	1.43	1.81	x/÷	55.6	43.3	80.7

	5	x/÷	1.6	1.48	1.82	x/÷	59.8	47.8	82.0
	6	x/÷	1.61	1.49	1.8	x/÷	60.7	49.4	79.9
	12	x/÷	1.49	1.43	1.58	x/÷	49.2	42.7	58.1
	18	x/÷	1.44	1.4	1.51	x/÷	44.3	39.5	50.5
	24	x/÷	1.41	1.37	1.46	x/÷	41.0	37.2	45.8
	30	x/÷	1.41	1.38	1.45	x/÷	41.1	37.7	45.4
SaA vGRF	3	x/÷	1.06	1.05	1.09	x/÷	6.3	4.9	9.4
	4	x/÷	1.06	1.05	1.08	x/÷	6.0	4.8	8.1
	5	x/÷	1.06	1.05	1.08	x/÷	6.4	5.3	8.2
	6	x/÷	1.06	1.05	1.08	x/÷	6.2	5.2	7.7
	12	x/÷	1.05	1.05	1.06	x/÷	5.5	4.8	6.3
SaA RFD	3	x/÷	1.26	1.20	1.40	x/÷	26.0	19.9	40.0
	4	x/÷	1.28	1.22	1.39	x/÷	28.2	22.4	39.4
	5	x/÷	1.24	1.20	1.32	x/÷	24.4	20.0	32.2
	6	x/÷	1.22	1.18	1.28	x/÷	22.1	18.4	28.0
	12	x/÷	1.16	1.14	1.18	x/÷	15.9	14.0	18.4
	18	x/÷	1.14	1.13	1.16	x/÷	14.3	12.9	16.1
Walk vGRF	3	x/÷	1.02	1.02	1.03	x/÷	1.9	1.5	2.9
	4	x/÷	1.02	1.02	1.03	x/÷	2.1	1.7	2.8
	5	x/÷	1.03	1.02	1.03	x/÷	2.5	2.1	3.3
	6	x/÷	1.03	1.02	1.03	x/÷	2.8	2.3	3.4
	12	x/÷	1.03	1.03	1.04	x/÷	3.1	2.4	3.3
	18	x/÷	1.03	1.03	1.03	x/÷	3.1	2.7	3.5
	24	x/÷	1.03	1.03	1.03	x/÷	3.1	2.7	3.4
	30	x/÷	1.03	1.03	1.03	x/÷	3.1	2.8	3.4
Walk RFD	3	x/÷	1.45	1.34	1.72	x/÷	45.2	34	72.2
	4	x/÷	1.5	1.39	1.71	x/÷	49.6	38.8	71.4
	5	x/÷	1.48	1.38	1.64	x/÷	47.6	38.3	64.4
	6	x/÷	1.49	1.4	1.64	x/÷	49.2	40.3	64.1
	12	x/÷	1.66	1.57	1.78	x/÷	65.7	56.6	78.3
	18	x/÷	1.59	1.53	1.68	x/÷	59.3	52.7	68.1
	24	x/÷	1.57	1.52	1.64	x/÷	57.4	51.8	64.5
	30	x/÷	1.55	1.51	1.61	x/÷	55.4	50.6	61.4
SaE vGRF	3	x/÷	1.06	1.05	1.09	x/÷	5.9	4.6	8.7
	4	x/÷	1.05	1.04	1.07	x/÷	5.4	4.4	7.3
	5	x/÷	1.06	1.05	1.07	x/÷	5.8	4.8	7.5
	6	x/÷	1.06	1.05	1.08	x/÷	6.1	5.1	7.6
	12	x/÷	1.07	1.06	1.08	x/÷	6.6	5.9	7.6
	18	x/÷	1.06	1.06	1.07	x/÷	6.4	5.8	7.1
SaE RFD	3	±	35.4	27.8	51.6	±	13.0	10.18	21.9
	4	±	31	25.2	41.5	±	10.9	8.05	17.4
	5	±	29	24.1	37	±	10.4	7.76	16.7
	6	±	28.7	24.3	35.5	±	10.5	7.39	15.9
	12	±	26.9	23.9	30.8	±	9.8	7.03	15.1
	18	±	25.7	23.4	28.7	±	9.2	6.52	14.0

Table 2: For the sake of brevity, a reduced number of trials were reported highlighting the initial changes in WS variation with the inclusion of additional single trials, and to highlight the extent of change in WS variation

calculated from a greater number of trials. TE, typical error for n cycles; LCL, lower confidence limit; UCL, upper confidence limit; random error is represented in absolute form; \pm , random error is represented in ratio form; \times/\div . The vGRF and RFD foot-drill data found to obtain a SB are not presented in table 2, hence the variation in the total number of trials presented between foot-drills.

Test-retest reliability

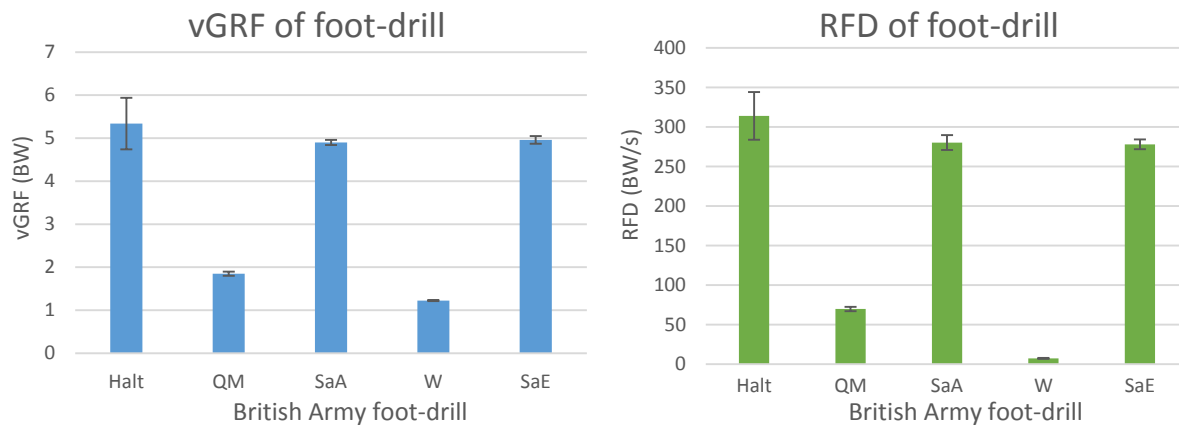
Table 3 illustrates the level of performance stability achieved for all foot-drills across the vGRF and vertical RFD variable. The maximum ICC value was recorded for the Walk vGRF condition (ICC = 0.92) with maximum ICC values ranging from 0.61 to 0.92. The number of trials required to achieve maximum ICC values ranged from 3 to 28 trials (mean \pm SD = 12.9 \pm 9.3 trials) across both predictor variables. With the exception of the vGRF SaE, vertical RFD SaA and Halt conditions, all remaining foot-drills achieved an ICC value ≥ 0.75 from 3 to 10 trials (mean \pm SD = 4.0 \pm 2.6). The vGRF variable illustrated greater levels of performance stability (mean \pm SD, ICC = 0.835 \pm 0.093) when compared with the vertical RFD variable (mean \pm SD, ICC = 0.73 \pm 0.79), suggesting that the vGRF variable could be defined as a more reliable measure with which to accurately determine changes in foot-drill performance. The maximum number of trials required to achieve an ICC of 0.80 from the remaining two testing sessions and the initial 8 trials from each session ranged from 3 to 16 trials (mean \pm SD = 6.8 \pm 5.5). Only the QM and Walk vGRF conditions achieved an ICC ≥ 0.85 from a total of 3 trials (mean \pm SD = 3.0 \pm 0.0 trials).

Table 3 – vGRF and RFD foot-drill ICC results

Variable (Unit or Ratio)	ICC Maximum (n cycles)	ICC	ICC (95%LCL)	ICC (95% UCL)	ICC 0.75 (n cycles)	ICC 0.80 (n cycles)	ICC 0.85 (n cycles)
Halt vGRF	5	0.821	0.659	0.929	3	4	--
Halt RFD	15	0.673	0.503	0.843	--	--	--
QM vGRF	28	0.912	0.843	0.963	3	3	3
QM RFD	28	0.802	0.677	0.911	3	20	--
SaA vGRF	8	0.810	0.670	0.920	3	8	--
SaA RFD	16	0.621	0.446	0.810	--	--	--
Walk vGRF	3	0.924	0.818	0.972	3	3	3
Walk RFD	3	0.791	0.552	0.919	3	--	--
SaE vGRF	4	0.699	0.456	0.872	--	--	--
SaE RFD	19	0.764	0.622	0.892	10	--	--
Mean (SD)	12.9(9.3)				4.0(2.6)	7.6(7.2)	3.0(0.0)

Table 3: represents the maximum number of trials required to achieve poor, moderate and strong levels of test retest reliability; -- indicates that the ICC value was never achieved. The minimum number of trials required to achieve ICC levels of 0.75, 0.80 and 0.85 were also calculated. Only the Walk and QM vGRF condition illustrated an ICC <0.90.

Figure 3 – Ground reaction forces of foot-drill



Normalised vGRF (BW) and RFD (BW/s) generated by all participants during all five foot-drills. Values are means and bars are SD.

DISCUSSION

The present study is the first to report reliability measures of the kinetic variables of British Army foot-drill. The initial aim of the present study was to determine the existence and magnitude of between-session and within-session systematic bias. In addition, this study has quantified the impact loading forces and loading rates associated with British Army foot-drill within an untrained male civilian population. The statistically significant ($P < 0.05$) between-session mean differences in vGRF and vertical RFD for SaA and SaE indicate that a single familiarisation session is required before collecting reliable foot-drill force data; suggesting that the key performance markers of selective foot-drills (SaA and SaE) may require more time to learn when compared with other foot-drills. The requirement of a single familiarisation session can best be explained by the novelty and complexity of foot-drill for untrained males. Initial analysis of the whole data set revealed within-session (between-trial) differences of the vGRF SaA and SaE conditions. However, after the removal of the first session data

no between-trial differences remained, suggesting that the systematic bias apparent in the vGRF data during the first testing session were large enough to influence the remainder of the data.

The second aim was to ascertain the magnitude of the within-subject variation in each of the variables. The levels of $\%CV_{te}$ reported for the vGRF and vertical RFD variables within the present study (figure 2a and 2b) are similar in magnitude to those reported by Floria *et al.*, [14] which examined the reliability of repeated trials ($n = 3$) of the GRF of two different countermovement jumps ($\%CV_{te}$ range: vGRF = 12.3% - 13.3%, range RFD = 74.6% - 77.4%). In addition, Copic *et al.*, [10] also revealed similar mean $\%CV_{te}$ values from repeated trials ($n = 3$) for GRF variables in vertical jump performance (mean $\%CV_{te}$: vGRF = 5.7%, RFD = 29.1%). As reported in previous reliability literature [8, 19], the $\%CV_{te}$ was found to reduce when the number of trials utilised to calculate the average score increased, with the greatest increases in reliability ($\%CV_{te}$) shown within the initial increase in the number of trials used to calculate the mean value.

Reductions in $\%CV_{te}$ (improved reliability) were apparent within the present study for the vGRF Halt, SaA, QM and vertical RFD SaE condition, with the greatest increases in reliability shown within the initial changes in the number of trials used to calculate the mean value. For example, an average $\%CV_{te}$ reduction of 0.97% was observed when using six trials compared with three trials, a further 0.35% average reduction by using seven trials compared with four trials, and an average reduction in $\%CV_{te}$ of 0.81% when using eight trials compared with five trials. Beyond eight trials, the use of additional trials of data to calculate the mean value across all foot-drills resulted in diminishing returns; for every additional trial utilised in the calculation of the mean values, the smaller the reduction in the $\%CV_{te}$ [8]. Similar average reductions in $\%CV_{te}$ were observed for the vertical RFD variable, however, these reductions did not show worthwhile improvements in levels of reliability across remaining foot-drills.

The final aim of this study was to determine the test-retest reliability of foot-drill force data to provide additional information to make decisions regarding the number of trials of data required to achieve

stable levels of performance, and to accurately track changes in foot-drill performance over time. However, it should be noted that ICC values at which test-retest reliability are deemed poor ($ICC \leq 0.75$), moderate ($ICC 0.75 - 0.85$) and strong ($ICC \geq 0.85$) are arbitrary values [25]. Nevertheless, the ICC is defined as more of an objective means of assessing the number of trials required to establish the stability of performance than other measures (i.e., sequential averaging), as it involves fewer arbitrary decisions when assessing performance stability [8, 20].

The initial interpretation of the ICC analyses shows that the vGRF Halt, QM, SaA and Walk condition achieved moderate to strong levels of test-retest reliability, with only SaE failing to achieve an ICC value ≥ 0.75 . Maximum ICC values for the vertical RFD variable range from 0.62 for SaA, to 0.80 for QM, illustrating poor to strong levels of test-retest reliability. However, strong levels of test-retest reliability were only achieved in QM and Walk. The QM, SaE, and Walk vertical RFD values achieved moderate levels of test-retest reliability, with Halt (range = 0.36-0.67) and SaA (range = 0.24-0.62) failing to achieve an ICC value ≥ 0.75 [16]. This finding suggests that multiple trials of foot-drill force data (mean \pm SD: vGRF = 8.5 ± 6.7 trials, RFD = 13.7 ± 12.9 trials) are required before maximum ICC values can be obtained.

It is recommended that ICC data should not be considered in isolation, rather, within-subject variability data should also be taken in to account when making decisions regarding the minimum number of trials required to accurately represent the GRF of foot-drill data as data can be adversely influenced by the homogeneity of the test sample, which will affect any interpretation of reliability [3, 8, 16, 19, 23]. Also, by considering the magnitude of the within-subject variation, the number of trials required to ensure a reliable assessment of each force variable can provide a measure of accuracy with which any future changes in vGRF and/or vertical RFD of foot-drill performance can be monitored [8].

This study has reported foot-drill mean peak vGRF and vertical RFD data similar to those reported in previous foot-drill research [5, 9] and are comparable with peak vGRF and vertical RFD apparent in

high level plyometric drills [29]; demonstrating that foot-drill represents a substantial mechanical load placed on the MSK structures of the lower-extremities. The Halt foot-drill exhibited the greatest mean peak vGRF (5.3 ± 0.6) and vertical RFD (313.9 ± 30.2) when compared with the remaining foot-drills, with SaE and SaA exhibiting vGRF and vertical RFD in excess of 4.9BW and 278.1BW/s, respectively (figure 3). In addition, selective participants were found to produce vGRF and vertical RFD values relative to the Halt foot-drill of 6.9BW and 825.1BW/s, respectively.

Recently, QM has been shown to exhibit comparable vGRF and vertical RFD values to running speeds of 3m/s (1.6BW) to 3.5m/s (1.3BW) [24]. In this study, QM was found to exhibit greater vGRF (1.8BW) and vertical RFD (69.3BW/s) values when compared with a normal walking gait (vGRF = 1.2BW, vertical RFD = 7.3BW/s). Previous (*in vivo*) research [22] has shown that high repetitive impact loading forces (≥ 3.0 BW) may produce tensile, shear and compressive strain-rates that may initiate bone damage at a microstructural level, resulting in single or multiple lower-limb stress fractures. Thus, the magnitude of forces and repetitive skeletal loading of foot-drill may significantly contribute to the high incidence rates of lower-limb MSK overuse injuries sustained by untrained male recruits, and significantly increase the risk of sustaining one or more lower-limb bone stress fractures during the initial weeks of BMT.

One limitation of the current investigation is the all-male sample. Previous biomechanical studies have demonstrated that recreationally active females exhibit distinct loading mechanics and lower-limb kinematics when compared with their male counterparts [5, 29]. Thus, it is unlikely that these results can be generalizable to a recreationally active female population. In addition, study participants performed foot-drill in a training shoe, whereas, foot-drill is usually performed in the combat boot. Due to a lack of CB readily available for this study, the kinetic variables of foot-drill reported may not truly reflect those experienced when wearing the CB. Nevertheless, the peak vGRF and vertical RFD of foot-drill are similar in magnitude to those reported previously in untrained samples [5, 9].

PRACTICAL APPLICATIONS

A pragmatic approach is recommended when deciding on the number of trials used to represent foot-drill force data [8, 19] considering the requirement of high test-retest reliability and acceptable levels of within-subject variation concurrently with the economic, practical and logistical concerns of collecting repeated trials/sessions of foot-drill data. As previously mentioned, the greatest increases in stability and reliability are shown within the initial changes in the number of trials used to calculate the mean ICC and %CV_{te} value; with diminishing returns in reductions in %CV_{te} data observed beyond eight-trials, with the achievement of a moderate level of test-retest reliability for each foot-drill of the vGRF variable, excluding SaE. Each one of the foot-drills (excluding SaE) relative to the vGRF variable demonstrated acceptable levels of reliability. However, in accordance with previous reliability literature [3, 8, 19] the magnitude of a variable's stability and reproducibility depends on its intended use, and subsequently, the researcher must determine whether it is sufficiently reliable to measure the smallest worthwhile change in an individual's performance.

The findings of the present study support the inclusion of a single familiarisation session specific to the SaA and SaE foot-drills. It was determined that the vertical RFD variables exhibited poor levels of reliability across foot-drills. Similar levels of reliability of the vertical RFD variable have been reported in previous literature [10, 14]. Nevertheless, it was determined that an average of eight-trials is required to achieve moderate to strong levels of reliability of foot-drill GRF data. The reliability of the vGRF and vertical RFD variable differed notably. However, in the majority of foot-drills there was a consistent trend for reliability to marginally improve when the average score of multiple trials was used as the measurement of interest.

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